EL Program: Fire Risk Reduction in Communities

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Strategic Goal: Disaster-Resilient Buildings, Infrastructure, and Communities

Summary: This program focuses on reducing two components of community fire risk: 1) increasing the fire resilience of wildland urban interface communities and 2) enhancing the safety and effectiveness of fire fighters. Wildfires that spread into wildland-urban interface (WUI) communities can be extremely costly in structural losses. The 1991 Oakland and 2007 Witch Creek fires in California resulted in property losses of $2.7B and $1.5B, respectively.[1] In 2009 the fire service responded to over 1.3 million structure fires[2] leading to 78,150 fire fighter injuries and 83 fatalities[3] at an estimated cost of $8 B.[4] This program combines lab- and field-scale experiments and observations with computer fire models to 1) characterize the WUI fire exposure, ignition, and fire spread in order to develop science-based standards, codes, and practices for fire resistant communities and 2) incorporate cyber-physical systems, and develop performance metrics and standards to enable integration of innovative technologies and provide safer protective equipment and more effective tactics for fire fighters.

DESCRIPTION

Objective: To develop and deploy advances in measurement science to improve the resilience of communities and structures to unwanted fires through innovative fire protection and response technologies and tactics by 2016.

What is the problem? Communities lack sufficient resilience[5] to resist and respond effectively to adverse events that range from a fire which involves a single structure to a wildland-urban interface fire that involves one or more communities. For a typical small community,[6] small-scale fires, typically involving a single structure, occur relatively frequently, 65 times a year, or roughly once a week. In contrast, significant wildland-urban interface fires occur relatively infrequently in vulnerable communities, less than once a decade.[7] Strategies for improving the resilience of a community to withstand a relatively infrequent, but large-scale high-consequence WUI fires are different from strategies mitigating relatively frequent, but smaller structure fires. Improving the resilience of communities for infrequent large WUI fires involves improving the fire resistance of the structures and entire communities. Reducing the fire risk in communities to frequent small-scale structure fires requires improving the ability to respond in terms of the safety and effectiveness of fire fighters.

Within the last 100 years in the U.S., six of the top 10 most damaging single fire events involving structures were WUI fires. The October 2007 southern California fires displaced residents of over 300,000 homes and resulted in over $1.8 B in insured losses.

Both the number of acres burned annually by wildland fires[8] and the number of houses located in the WUI[9] are increasing. The total cost of WUI fires in 2009 was estimated to be over $14 B.[10]

In order to improve the fire resilience of communities, advances in measurement science are needed to identify and characterize the exposure conditions and mechanisms that result in a high risk of structure ignition across a range of WUI community types and conditions. Also, to date, no thorough study that measures the effectiveness of current risk mitigation practices, whether through ignition resistant building components or community design to limit fire spread, has been conducted. Improving the fire resistance of communities has been identified as a critical issue by the National Science and Technology Council report on disaster reduction,[11] Western Governors Association (WGA),[12] the Office of the Federal Coordinator for Meteorological Services (OFCM) and Supporting Research,[13] and the Government Accountability Office.[14]

A second component of community resiliency involves an ability to respond effectively to structural fires, both urban and wildland urban interface. In 2009, the fire service responded to over 1.3 million fires[15] that resulted in 78,000 fire fighter injuries and 83 fatalities[16] with an estimated cost of $8 B.[17] In order to reduce the number of fire fighter fatalities and injuries, science-based performance metrics are necessary to improve fire fighter safety and enhance fire ground effectiveness. For both equipment and tactics, it is critical for performance to be measured and evaluated in a scientifically sound manner. The lack of adequate measurement science directly impacts the protective equipment and tactics utilized by the over one million fire fighters in over 32,000 fire departments in the US. The National Fire Research Agenda Symposium,[18] which was attended by over 50 organizations,[19] including the fire service, International Association of Fire Chiefs (IAFC), International Association of Fire Fighters (IAFF), National Volunteer Fire Council (NVFC), manufacturers, Department of Homeland Security (DHS), and US Fire Administration (USFA), identified and prioritized research needs for fire fighters. Some of the "urgent and critical issues" that were identified included improved respiratory protection, situational awareness technology, tactical decision aids, lessons learned/fire reconstruction, and fire ground strategies that would reduce injuries and fatalities. Over 60 participants at the 2009 NIST Innovative Fire Protection Workshop[20] identified tactical decision aids, improved respirators, and enhanced turnout gear as high priority research needs. Emerging cyber-physical systems including fixed and mobile robot technologies, sensors and controls in buildings, and fire apparatus and equipment will enhance productivity and situational awareness, allowing improvements in both fire fighter safety and effectiveness.

Why is it hard to solve? It is hard to improve the fire resilience of communities because it requires the ability to withstand, respond, and recover from community-scale and structure-scale events. Each scale presents different challenges to the community. On the community scale, where there may be hundreds of structures involved, the WUI fire behavior is difficult to predict due to the large range of physical and time scales (1 m to 1000s m, minutes to 100s of hours). The extreme conditions of WUI fires do not easily allow traditional observation and measurement of fire behavior and structure ignition.

Destructive WUI fires often occur in extreme environmental conditions, such as high winds and hot, dry weather, resulting in spread rates and fire intensities that are difficult to reproduce experimentally or measure with field deployable instrumentation. Developing the measurement science to adequately characterize firebrands (an important contributor to structure ignition) from WUI fuels is challenging due to the range of WUI fuel types and fire conditions. Finally, post-incident assessment of WUI fire behavior must account for the influence of a range of environmental (e.g., extreme winds) and human factors (e.g., fire fighter and homeowner actions).

Operating conditions experienced by fire fighters are extremely harsh, impacting different technologies in different ways. Wet, high thermal flux, and high temperature scenarios adversely affect the performance of thermal imagers, protective clothing, and respirators. The wide range of common construction materials (wood, concrete, or steel) and configurations (single family residence, a commercial warehouse, or a high rise office) creates complexity for fire fighting technologies such as locator/tracking systems, tactical decision aids, and positive pressure ventilation. For protective clothing, the metrics must include high heat flux and moisture, but for locator technology, the metrics needs to include signal attenuation caused by wood, steel, and concrete.

How is it solved today, and by whom? There are two major approaches to improving the fire resilience of WUI communities 1) wildland fuel treatments (by Federal, state, or local agencies) and 2) residential fuel management (structures and vegetation) treatments (by homeowners and communities). Both of these approaches are rule based or prescriptive. Since very little post-WUI fire incident analysis has been conducted to evaluate risk, their effectiveness is generally unproven (from both a risk reduction and an economic cost/benefit point of view). There are no other organizations beyond NIST that have developed a comprehensive and coordinated science-based effort on WUI fires.

In terms of improving the safety and effectiveness of fire fighters, the measurement science issues have not been solved. The fire service is not able to develop their own performance metrics and standards because they do not have the technical training or resources. Manufacturers have the resources to conduct performance tests, but are unlikely to release data that places their product at a disadvantage in a highly competitive market. The National Institute for Occupational Safety and Health's (NIOSH) National Personal Protection Technology Laboratory has expertise in respirator certification, but it has no capability to expose protective equipment to high temperature conditions. National Fire Protection Association's (NFPA) Fire Research Foundation prioritizes research needs for its standards committee, but since the Foundation has limited funding and no research facilities, its role in meeting measurement science challenges is more of a coordinating function. The fire service and residential construction have historically not been the first to adopt new technologies, such as systems that take advantage of cyber-physical components. For the past ten years, EL has been an active leader and participant in developing measurement science for fire service technology.

Why NIST? The objectives of this program are consistent with the National Institute of Standards and Technology Act, which directs NIST to conduct basic and applied fire research into the behavior of fires in buildings and design concepts to provide increased fire safety.[21] This program supports EL's Disaster-Resilient Buildings, Infrastructure, and Communities Strategic Goal to reduce the risk and enhance the resilience of buildings, infrastructure, and communities to natural and manmade hazards through advances in measurement science. This program utilizes EL's core competencies in a) fire protection and fire dynamics within buildings and communities, and b) resilience and reliability of structures under multi-hazards to provide measurement science that will enable 1) the development of new standards and risk assessment tools that reduce the destructive impact of wildfires on WUI communities and 2) the reduction of fire fighter and civilian fatalities and injuries and property losses due to fire.

NIST has unsurpassed experience in fire testing and is a trusted source of unbiased, science-based, quantifiable recommendations to standards developing organizations including NFPA, ASTM International (ASTM), International Organization for Standardization (ISO), and International Code Council (ICC). This program also advances the development and implementation of new technology by providing measurement science that promotes U.S. innovation and competitiveness.

What is the new technical idea? There are two new technical ideas. The first considers the resiliency of WUI communities in addressing large-scale and infrequent WUI fires and the second considers fire fighting safety and effectiveness. For WUI community fire resilience, the new technical idea is to implement a mitigation framework for both individual structures and for communities. The mitigation framework features three components, 1) characterizing the possible exposures, 2) understanding the response of the structure, sub-division, and community, and 3) designing the structure, sub-division, and community to withstand potential exposures. Characterizing the exposure requires a greater understanding of burning rate, thermal flux, ember generation of wildfires, as well as the effects of wind, moisture, and terrain. This needs a coordinated science-based effort comprised of targeted laboratory experiments, field measurements, post-WUI fire analysis, and a range of models including vegetation and structure fire models. Combining the exposure with the response of the structure and community will enable the development of measurement science-based tools for the design of fire resistant structures and communities. This work will form the basis for improved WUI fire building test methods, standards, and codes. In addition, the effectiveness of existing and new WUI fire risk assessment and risk mitigation approaches will be assessed through pre- and post-fire field studies.

The new technical idea for fire fighter safety and effectiveness is to incorporate cyber-physical systems and to develop performance metrics and standard test methods that directly relate to the operating environment and tasks performed by fire fighters. If relevant performance data is available for existing equipment or tactics, then a meaningful performance metric can be developed, but too often the necessary data is not readily available. For respirators, NIOSH has collected data at ambient temperatures, but no data is available for high temperature exposures. For respirator lenses, the current standard requires exposure in a 95^{o} C oven, but there is no technical basis for this requirement. For protective clothing there is a significant amount of data for new protective clothing, but very little data on used or soiled clothing. Lab- and full-scale tests will provide the necessary data to generate comprehensive metrics for existing equipment. For other technologies such as positive pressure fans (ventilation) and hose nozzles (suppression), the equipment is relatively simple, but best practices are not clear. Computer models and full-scale experiments that generate the required data will facilitate development of situationally-appropriate performance metrics and tactics. For emerging technologies, industry often has little understanding of the operating environment or requirements of the fire service. Lab- and full-scale tests in combination with science-based metrics will allow industry to evaluate and improve their own products and develop new technology. Cyber-physical systems offer new opportunities to enable the fusion of emerging technology with building systems, and the fire service to improve both fire fighter safety and effectiveness.

Why can we succeed now? The program can improve the resilience of communities for WUI fires because: 1) standardized post-fire data collection provides a better understanding of the fire exposure, 2) continuing advances in affordable computational resources (especially multiprocessor computers) reduce time and cost of developing fire spread models, 3) stakeholder support for post-fire analysis and ongoing experiments including firebrand studies,[22] and 4) end-user interest and commitment (as reported by the WGA[8] and OFCM[9]; and by external funding) to improve WUI and wildland fire behavior models.

The program can improve the fire resilience of structures, because the next generation of fire fighters is more accepting of new and innovative technology. In addition, new technologies such as tactical decision aids and locator/trackers are being developed and coming on-line. Other technologies, including protective clothing and respirators, have seen recent progress in performance predictive modeling. NIST staff has the necessary lab- and full-scale experimental experience and the computer modeling abilities to develop the required performance metrics and standard testing protocols to evaluate existing technology, integrate new technology, and provide simulations and training programs.

What is the research plan? The research plan includes three thrusts 1) improve fire resilience of wildland urban interface communities, 2) improve the safety and effectiveness of fire fighters, and 3) cross cutting research through Fire Research Grants.

The first research thrust addresses the need to improve the resiliency of communities to infrequent, but large-scale adverse WUI fires incidents and is composed of three parts or phases that focus on the need to 1) reduce fire spread among structures within a community, 2) reduce the ignition of structures, and 3) incorporate research results into WUI building, fire codes, and standards. Phase 1 involves a project to reduce fire spread within the WUI community. The first steps are to collect data to characterize the fire exposure during a WUI fire and to characterize which components of the structures and the community are most vulnerable, how the fires are spreading, as well as how wind, moisture, and terrain affect the fire spread. This effort will characterize the fire exposure through collection, analysis, and archiving[23] of post-fire data and begin to incorporate wind into Wildland Fire Dynamics Simulator (WFDS).[24] This will involve a coordinated science-based effort comprised of field measurements and post-WUI fire analysis. Phase 2 involves a project to reduce the ignition of structures and sub-divisions within a community. Reducing the ignition requires a greater understanding of structure ignition mechanisms, (which structure components ignite first? what roles do structure and vegetation fuels play in structural ignition?). This will need an integrated science-based effort comprised of targeted laboratory experiments and a range of models including vegetation and structure fire models. Building on the analysis from the Witch Creek Fire,[25] where decking components were noted as early igniting components, this project will focus on understanding the vulnerability of wood decking and begin to incorporate component ignition into WFDS. The third phase builds on the August 2012 WUI Building and Fire Codes Technical Solutions Implementation Workshop by developing a Guide for Implementing Technical Solutions and beginning to develop science-based performance metrics for mitigation ofWUI ignition and fire spread. This will involve transferring the improved characterization of exposure and response of structures and communities to building and fire code, and standards committees.

The second research thrust is to improve the resiliency of communities and is composed of three parts or phases, which focus on the need to improve the safety and effectiveness of fire fighters through improved (1) equipment, (2) operational tactics, and 3) smart fire fighting. The first phase involves a project to improve the high temperature performance of fire fighter equipment by increasing the level of performance, efficiency, and safety of fire fighters. Test methods are developed to assess the performance of fire fighter equipment under realistic high temperature, rough duty, environments. The project will focus on the performance of fire fighter self-contained breathing apparatus (SCBA), fire fighter electronic equipment including Radio Frequency Identification (RFID) and fire fighter locators, and fire fighter protective clothing. Phase two involves fire behavior. Fire fighter tactics are driven by tradition and experience, not fire science. Measurements are needed to determine the capabilities and limitations of fire fighting techniques in real scale structures to provide a basis for tactics. This project will focus on ventilation and suppression tactics for structure fires and the education and training of fire fighters. The third phase, smart fire fighting, involves using cyber-physical systems to enable the combination of emerging technology with building systems, and the fire service to improve both fire fighter safety and effectiveness. Implementation of this new idea will use three integrated platforms: (a) smart building technology and robotics, (b) smart firefighter equipment and robotics, and (c) smart fire department apparatus and equipment.

The third thrust addresses the need for cross-cutting research that addresses key aspects of the national fire problem and supports the strategic objectives of the fire programs within EL's Disaster-Resilient Buildings, Infrastructure, and Communities Goal. Thirteen grants and cooperative agreements provide financial support to researchers external to NIST on a range of topics, including the modeling of wind and wildfires, multi-scale burning models for charring polymers, fire risk methods, nano-material fire retardants, evacuation of high rise office buildings, and the coupling of wildland urban interface fires to geographic information systems.

How will teamwork be ensured? The Program involves staff from each group in the Fire Research Division, from the Applied Economics Office, and groups within the Materials and Structural Systems Division, and Physical Measurement Laboratory's Electromagnetics Division (Boulder). A series of communications were conducted with staff on program direction and project milestones through four meetings and a program review. Interaction between team members will be encouraged through informal and formal sharing of project results through individual meetings coordinated by the Program Manager, through information sharing at EL Seminars, and through team meetings.

What is the impact if successful? If successful, this program will a) improve the fire resilience of the over 70,000 communities[26] at risk to WUI fires and b) enhance the safety and effectiveness of the 1.25 million fire fighters in the U.S.. It is anticipated that more than ten individual codes, standards, and practices will be created or improved by this program in the next five years (see standards strategy below). Project outputs, outcomes, and impacts are aligned with program objectives. The measurement science results will enable program impact ultimately expressed through improved fire loss statistics.

Metrics for measuring the impact on WUI communities involve tracking the proportion of structure ignitions and the extent of fire spread within WUI communities.[27] Pre- and post-fire surveys of communities that have (and have not) implemented building and fire codes to improve WUI fire resistance will allow assessment of the impact of improved fire resilience. It is anticipated that once implemented by communities, the improved fire resilience will reduce the vulnerability to ignition and fire spread in WUI communities by over 25%, preventing annual losses of 1200 structure fires and reducing WUI fire losses by over $3 billion.[28]

Metrics for fire fighting safety and effectiveness involve monitoring the number of fire fighter fatalities and injuries[29] and the extent of uncontrolled fire spread after the arrival of the fire department.[30] Fire statistics[31] for communities that have and those that have not adopted enhanced safety and effectiveness standards and practices will be used to evaluate the impact of this research program. It is estimated that once adopted by communities, the improved safety and effectiveness of fire fighters will reduce the number of injuries by 25%, decrease the number of secondary structures ignited, and reduce fire losses and fire protection costs by over $2 billion per year.[28]

Recent impacts for improving fire resilience of WUI communities include 1) the adoption of the NIST standardized ember generator by the Insurance Institute of Business and Home Safety (IBHS) which facilitates standardized testing of roofing, siding, and glazing materials, 2) the adoption of the NIST WUI I[32] and WUI II[33] post-fire data collection methodologies, which allow better characterization of exposure and response of structures to WUI fires by:

- CALFire in California
- Texas Forest Service in 2011 in Amarillo and other locations.
- US Forest Service (USFS) Region 8 (Southern US) (in process of adoption).
- National State Foresters Association (Proposal for adoption of WUI data collection m*ethodology by invitation,* June 2011).

- National Wildfire Coordinating Group (has promoted adoption)
- NFPA and ICC Codes and standards (adoption has been proposed)
- A significant number of additional partnerships have been developed.[34]
- Bastrop Complex Fire – NIST/USFS data collection methodology used for documentation and analysis of worst WUI fire in Texas history

Recent impacts for improving safety and effectiveness of fire fighters include 1) existing NFPA standard modified for high temperature performance of Personal Alert Safety Systems (PASS) devices, 2) the new NFPA 1801 standard created for thermal imaging cameras, 3) the existing NFPA 1981 standard modified for high temperature performance of self-contained breathing apparatus lenses (SCBA), and 4) new tactics for fire ground ventilation adopted by many large urban fire departments and fire service training developers. The fire safety equipment industry now manufactures all PASS systems and all thermal imaging cameras to meet the new standard. The new ventilation tactics for both positive pressure ventilation and wind-driven fire have been adopted by a number of major fire departments including New York City and Chicago. DHS is now funding fire departments to purchase ventilation equipment to implement these new tactics. Research on the high temperature performance of breathing apparatus lens has developed new performance tests which enables the replacement of all existing lens with substantially better performing within the next two years.

WUI stakeholders include homeowners, homeowner associations, city fire departments, Federal and state fire officials, building material manufacturers, homebuilders, standards organizations, and fire researchers. An MOU with California Department of Forestry and Fire Protection (CALFIRE) supports standard test methods and the development of community-scale risk assessment and risk mitigation methods. It is important to note that California is a key stakeholder and nationwide leader in WUI building codes and standards. Additional MOU's with IBHS, the ICC, and the USFS are being established. The establishment of national data collection response teams is currently being discussed with the USFSand this would provide high quality data over a broader range of WUI fires.

Fire service stakeholders include the public, building owners, fire fighters, municipalities, other Federal agencies, and standards development organizations. NIOSH's[35] National Personal Protective Technology Laboratory has collaborated in the development of high temperature exposure metrics for respirators and improved testing protocols for PASS device alarm signal performance. IAFF[36] has partnered and collaborated on research involving improved protective clothing. IAFC[37] has assisted in the development of programs to transfer research results to the fire service via NIST's FIRE.GOV newsletter. NFPA has teamed with EL on positive pressure ventilation, protective clothing, thermal imaging cameras, and high temperature exposure of radios and respiratory masks. DHS[38] continues to support improved safety standards for fire fighter equipment.

This program is developing performance metrics to assess program effectiveness. Candidate metrics for WUI communities involves tracking the number of structural ignitions and the extent of fire spread to additional structures within WUI communities during fire events.[39] Potential metrics for safety and effectiveness involves monitoring the number of fire fighter fatalities and injuries[40] and the extent of uncontrolled fire spread after the arrival of the fire department.[41]

What is the standards strategy? The standards strategy for the Fire Risk Reduction in Communities Program emphasizes critical standards for improving the fire resistance of communities to wildland-urban interface (WUI) fires: a) Standardized post-fire data collection and exposure scale for characterizing building, parcel and community WUI fire resistance performance standards (FY 2012), b) Ember ignition resistance test methods for characterizing the fire performance of key building elements, such as decking, window glazing, roofing, etc. (FY 2014), and c) Evaluating the economics of community-based fire mitigation (FY2015). The program also focuses on standards to improve the safety and effectiveness of fire fighters: a) New thermal exposure test methods for existing self-contained breathing apparatus (SCBA) (FY 2012), b) Standardized alarm sounds for Personal Alert Safety System (PASS) devices (FY 2013), c) Durability test standards for fire fighter protective turn-out gear (FY 2013), d) Standards for fixed and mobile fire sensing and suppression performance (FY2014), e) Standard tactics for non-mechanical ventilation of structures during fires (FY 2015), and f) Test methods for the high temperature performance of portable radios (FY 2016).

In FY 2011, the program re-evaluated its participation in codes, standards, regulations, and practices to maximize impact, and ensure alignment with the EL mission. In previous years, program researchers had participated in at least 44 committees. To better focus resources on top standards development needs, researchers resigned from 19 committees. For FY 2013, the remaining 25 committees provide better alignment with the EL mission to promote innovation and industrial competitiveness in areas of critical national priority. The high priority standards work leverages EL core competencies in fire protection and fire dynamics within buildings and communities, and the resilience and reliability of structures under multi-hazards. The standards, codes, and practices committees include broad participation from fire service, fire equipment manufacturers, testing laboratories, federal and state fire officials, building material manufacturers, and building and fire code officials.

It is expected that the following standards and practices will be adopted: 1) Standardized post-fire data collection methods to be incorporated into standard practice by the CALFIRE and the Texas Forest Service (2012); 2) Convective oven and radiant panel lens test procedures for SCBAs to be included in the NFPA 1981 Standard for Open-Circuit SCBA for Emergency Services (2013); 3) Alarm sound standards for PASS devices to be incorporated into NFPA 1982 Personal Alert Safety Systems (2014); 4) Protective turn-out gear durability standards included in NFPA 1971 Standard for Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting (2014); 5) Ember ignition test method to be incorporated into new ASTM E05.14.03.XX standard (2014) and subsequently into existing ICC WUI Building Code (IWUIC) (2015); 6) ASTM Standard for Fixed and Mobile Fire Sensing and Suppression (2014); 7) model to evaluate effectiveness of current fire protection for WUI communities, and 8) ventilation tactics to be included in NFPA 1410 Initial Emergency Scene Operations (2016). Many of these standards and practices, 1-4, & 8, will be used by municipalities and fire services to improve the safety and effectiveness of fire fighters. Other standards, 1, 5, & 7, will be used by building and fire code officials to improve the fire resistance of WUI communities.

Program staff lead and participate on committees aligned with standards development needs. Through work on key committees, technical results from this program support strategic improvements to existing and emerging standards, codes, and practices. Examples of standards leadership by program staff include membership on the NFPA Technical Correlating Committee on Protective Clothing and Equipment (which directs all NFPA standards on protective equipment, tactics, and training for fire fighters), and membership of the Board of Director's for the Society of Fire Protection Engineers. Researchers also collaborate with other Federal and state agencies to develop and implement standards and practices. Examples include working with US Fire Administration & National Institute for Occupational Safety and Health (SCBA respirators), and US Forest Service (WUI fire models), and California Department of Forestry and Fire Protection & Texas Forest Service (post-fire data collection). In addition to working with standards development organizations, program researchers organize and host workshops to identify and prioritize research needs to support existing standards or development of new standards. Examples of workshops include Thermal Imaging Research Needs for First Responders (2005), Real-Time Particulate Monitoring: Detecting Respiratory Threats for First Responders (2007), Emergency First Responder Respirator Thermal Characteristics Workshop (2010), Vulnerabilities of Decks to Ignition by Firebrand Showers (2011), and Urban and Wildland-Urban Interface Fires: Japan/USA Research (2011 & 2012).

Standards that have benefitted from recent NIST technical contributions include NFPA 1982 Standard on Personal Alert Safety Systems (2007 edition), NFPA 1801 Standard on Thermal Imagers for the Fire Service (2010 edition), and NFPA 1981 Standard for Open-Circuit Self-Contained Breathing Apparatus for Emergency Services (2013 edition). Regulations that have incorporated NIST procedures include the California Code of Regulations – Chapter 7A WUI Building Standards (2009 Supplement to 2007 Edition). Standards that are currently being balloted, but not yet adopted include ASTM E05.14 Fire Brand Resistant Building Vents. The NFPA and ASTM standards are used nationally, while the California Code of Regulations is a model often adopted by others states.

How will knowledge transfer be achieved? Awareness of the program among stakeholders and fellow researchers will occur through collaboration with NIST guest researchers, recipients of fire grants, NIST post-docs, conferences, workshops, and the archival literature. Transfer of end products (e.g., fire behavior and economic models, equipment standards, laboratory and field measurement techniques, post-fire assessment methodologies, fire ground tactics, and databases) will occur through working relationships with end users, standards committees, and other stakeholders.

For the research thrust on the fire resistance of WUI communities, the research will also result in a nationwide distribution of improved standards, codes, and practices.

Relationships have already been developed, for example, with the United States Forest Service (USFS), CAL FIRE, a southern California homeowners association, the office of the California State Fire Marshall, and the City of San Diego Fire Department. In addition, program members are part of the NFPA's Forest and Rural Fire Protection and the ASTM E5 standards committee on WUI fire exposure.

For the research thrust to improve safety and effectiveness of fire fighters, program results will be disseminated to customers and stakeholders through archival journal articles, conference proceedings (papers & posters), CD/DVD media,[42] web sites,[43] reports on the web[44] downloadable software[45] and participation in fire service conferences,[46] technical conferences,[47] workshops, standards, codes, and technical committee meetings. Guest workers from the fire service, authorities having jurisdiction (AHJ), and post-docs from universities will allow exchange of experience and knowledge.

MAJOR ACCOMPLISHMENTS

Outcomes:

Increased Fire Resistance of WUI Communities

- First generation rapid response instrumentation co-developed and tested.
- Unique experimental apparatus developed:
  - NIST Firebrand Generator,
  - NIST Dragon's LAIR (Lofting and Ignition Research) Facility.
- New capability, in collaboration with CALFIRE, to determine firebrand size distribution from *actual* WUI fires using digital burn pattern analysis.
- Results of NIST comparison testing protocol included in new test standard for firebrand resistant building vents (ASTM E05.14.06 Vents Subcommittee).
- Development of NIST WUI data collection methodologies
- Economic model (theoretical) of community-based mitigation accounting for the spatial spillover of individual homeowner mitigation efforts.[48]
- Validated physics based models for fires in grasslands and isolated trees.[49,50]
- A GIS data library to facilitate WUI community wildland fire risk analysis.
- First stage of GIS-based tool for mapping WUI fuels and creating fire behavior model inputs using remote sensing data.

Improved Safety and Effectiveness of Fire Fighters

- Self-Contained Breathing Apparatus Lens Exposure Test Method- incorporated in the 2013 edition of National Fire Protection Association (NFPA) 1981 *Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services.*
- National Fire Protection Association issued *Alert Notice for SCBA Lenses May Deform or Degrade in Severe Fire Fighting Conditions* to inform the fire service of the potential effects of certain fire environmental conditions on facepiece lenses in NFPA-compliant SCBAs. NFPA believes it is extremely important for the fire service to be aware of the conditions and the possible consequences of those conditions. NFPA states that fire departments should consider upgrading to or purchasing SCBAs which are certified as compliant to NFPA 1981, 2013 Edition, when they become available.
- All current SCBA ensembles will require a replacement lens in order to meet new performance requirements in the 2013 Edition of NFPA 1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services.*
- Research and Data Collection in the Fire Service. Madrzykowski, D., Understanding and Implementing the 16 Fire Fighter Life Safety Initiatives, Ch 3. Fire Protection Publications, Stillwater, OK, July 2010.
- Infrared Imager Technology- Laboratory facility capable of evaluating performance of thermal imaging cameras.
- Automatic Sprinklers- DVD video and report on Impact of Sprinklers on the Fire Hazard in Dormitories released as part of US Fire Administration initiative to improve fire safety in college housing, January 2010
- Positive Pressure Ventilation – Research Video and Reports:[51] 7 reports, 24 hours of video, and a slide presentation distributed in a 2 DVD set, over 40,000 DVDs distributed.

- Fire Fighter Protective Clothing-Database demonstrates insufficient transmission through new or aged outer shells to cause UV induce degradation of Thermal Liner or Moisture Barrier
- Performance metrics and test methods developed for predicting the service life of fire fighter protective clothing. These metrics address the effects of ultra-violet exposure on the performance of commercially available protective clothing demonstrate that 50% of the physical strength of the outer shell is lost within 5 years of service.
- Characterization of Fire Fighter Respirators- experimental facility consisting of a breathing simulator, test head, fire fighter SCBA, aerosol generator, and pressure sensor assembled to study pressure drop and protection factor from three leak sizes.
- Locator / Tracker Technology- workshop session and working group on evaluation of locator/tracking systems at annual WPI Precision Personnel Location Systems Workshop, Aug., 2010.
- Performance Metrics for Critical Electronic Equipment for Fire fighters -Capability to expose electronic equipment to controlled temperatures while monitoring functionality.[52]
- Hose Stream - First order fire suppression model with water calibrated and being incorporated into FDS.

Recognition of EL: The researchers have been recognized in a number of ways due to their program activities. These include numerous invited talks at international and national venues, invitations to participate in key national WUI and wildland fire related panels and committees,[53,54,55] press interviews,[56] an international research fellowship (Manzello, Japan), invitation (Maranghides) to join an international team of researchers in response the 2009 Australian bushfires in Victoria. Manzello served as an Invited Guest Editor for Wildland Urban Interface Fire Ignition for two archival journals, *Fire Safety Journal* and *Fire Technology.*

The Charleston Sofa Super Store Technical Study was featured on ABC, CBS, and NBC in Charleston, SC (Bryner). International Association of Arson Investigators developed a training module based on the Charleston Technical Study, www.cfitrainer.net/. The positive pressure ventilation work was reported on local TV (Chicago and NY) and national networks (ABC & FOX) (Madrzykowski). Positive pressure ventilation research has also been on the web at Firehouse.com and FireEngineering.com. Burn pattern research results have been highlighted in presentations on www.cfitrainer.net/. Madrzykowski has been named *Honorary Battalion Chief* by FDNY (2012) for his contributions to developing advanced fire fighting tactics. NIST was awarded the 2012 *Outstanding Accomplishment Award* by the International Association Arson Investigators for its fire science contributions to arson investigation. Madrzykowski was presented with the 2012 *Dr. John Granito Award* by the University of Oklahoma for his contributions to fire fighter training and safety.

[1] "How Much Do Wildfires Cost in Terms of Property Damage," Scientific American, June 2011.
[2] Karter, M.J., Fire Loss in the United States During 2009, National Fire Protection Association, Quincy, MA, August 2010.
[3] Karter, M.J., and Molis, J. L., US Firefighter Injuries – 2009, National Fire Protection Association, Quincy, MA, August 2010.
[4] "The Economic Consequences of Firefighter Injuries and Their Prevention," NIST GCR 05-874, March 2005.
[5] Disaster-resilient communities exhibit the ability to withstand an adverse event and/or recover to target levels of service delivery and quality within target amounts of time. (Risk Assessment and Management for Critical Asset Protection, RAMCAP, ASME Innovative Technologies Institute**).**
[6] Population of community 5000 or less, NFPA Total Fire Statistics 2009.
[7]Assuming 50,000 high risk communities and about 5000 structures burned per year; population of community 5000 or less, 1000 homes/community
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[27] Ignition of and fire spread on structures normalized by the number of total structures for similar WUI fires.
[28] Reduction is describe in more detail in terms of losses and preventable fire burden in *Reducing the Risk of Fire in Buildings and Communities: A Strategic Roadmap to Guide and Prioritize Research*, NIST SP 1130, April 2012.
[29] Fatalities and injuries normalized by the number of fires on an annual basis.
[30] After arrival of fire service, accounting for fire spread before arrival, and normalized by total area that the fire might spread over without intervention.
[31] For example, fire service injuries and fatalities and next structure ignited collected by National Fire Incident Reporting System (NFIRS) at US Fire Administration or fire statistics developed by National Fire Protection Association (NFPA).
[32] WUI I data collection is paper-based form filled out by trained observers after a fire.
[33] WUI II data collection is a electronic-based series of forms and maps linked via GIS filled out by trained observation teams after a fire.
[34]
- USFS FERA support for characterizing exposure and for WUI data collection
- NFPA FIREWISE Program – A joint effort will result in a revised and improved Firewise checklist.
- Partnerships with states agencies that have significant WUI problem areas: CA, FL and TX are close partners for technology transfer.
- Joint Fire Science Program – dissemination of WUI methodology, structure ignition vulnerabilities and hazard

mitigation solutions.
- Committee on a National Cohesive Strategy as requested by US Congress (*by invitation*): active participation in Wildland and WUI data collection framework and Public Safety, Property Loss, & Social/Community vulnerability framework development.

[35] National Institutes for Occupational Safety and Health.

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[37] International Association of Fire Chiefs

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[41] After arrival of fire service, accounting for fire spread before arrival, and normalized by total area that the fire might spread over without intervention.

[42] CD/DVD Media - www.fire.gov participation in technical conferences (Fire Department Instructors Conference and Fire and Rescue International), workshops, standards, codes, and technical committee meetings(NFPA and ASTM.

[43] Websites - www.bfrl.nist.gov & www.fire.gov.

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[45] Downloadable Software - www.bfrl.nist.gov/info/software.html & fire.nist.gov/fds/ .

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